US-PAT-NO: 6157621
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TITLE: Satellite communication system

Abstract Text - ABTX (1):

The Satellite Communication System disclosed in the specification is a dynamic constellation (C) of satellites (S). The present invention is capable of offering continuous voice, data and video service to customers across the globe on the land, on the sea, or in the air. The preferred embodiment of the invention comprises a low Earth orbit satellite system that includes 40 spacecraft (S) traveling in each of 21 orbital planes at an altitude of 700 km (435 miles). This relatively large number of satellites employed by the preferred embodiment was selected to provide continuous coverage of the Earth's surface at a high minimum mask angle (1230a) of forty degrees. Each of the individual 840 spacecraft (S) functions as an independent sovereign switch of equal rank which knows the position of its neighbors, and independently handles traffic without ground control. The satellites (S) are capable of transporting calls to millions of customers using portable (P), mobile (M) and fixed (F) residential and business terminals, and gateways (G) to public phone networks. The constellation uses the 20 and 30 GHz frequency bands for communications between Earth and the constellation (C), and the 60 GHz band for communicating among the satellites (S). The present invention is designed to support in excess of 2,000,000 simultaneous connections, representing over 20,000,000 users at typical business usage levels, and over 350 billion minutes of use per year. Only a system such as the preferred embodiment, which utilizes 840 satellites at a preferred minimum mask angle of forty degrees, can accomplish these challenging objectives.

Brief Summary Text - BSTX (17):

This specification is accompanied by two Appendices, A and B, recorded on two sheets of microfiche which contain software that may be employed to practice the invention. The first software listing may be used to implement that portion of the present invention which pertains to Autonomous Orbit Position Determination. The second software listing may be used to implement that portion of the present invention which pertains to Adaptive Routing. Both software programs were written for conventional personal computers and may be run on IBM Compatible systems employing a conventional DOS operating system. These software programs simulate selected embodiments of the present invention which are described below in full detail. The programs enable a person of ordinary skill in the arts to which the present

invention pertains to practice the invention without undue experimentation.

Brief Summary Text - BSTX (21):

Some extension of the century-old centralized telephone switching infrastructure has been achieved using geostationary satellites. These spacecraft, however, offer additional communications capabilities that are quite limited. Since these satellites operate in equatorial orbits, they are not accessible to customers located in high latitudes. Because they must share their orbit with many other services, their number is restricted to a relatively small population. Since all of these spacecraft occupy a single circular orbit, they can not be connected together in a geodesic network. A geodesic network, which could provide enormously greater capacity, must be generally spherical in shape. Geostationary satellites also suffer from a very serious disadvantage--the distant altitude of their orbits. These satellites are so far from Earth that the signal takes about one-quarter of a second to traverse the nearly 50,000 miles (80,000 km) along the round trip from the ground up to the satellite, and back to the ground. The delays sensed by the telephone user's ear that are introduced by this long round trip are not only annoying, but can render some conversations which are relayed between more than one geostationary satellite virtually unintelligible. Radio signals which are exchanged between a ground station and a geosynchronous satellite may also be impaired by this great round trip distance. A telephone customer on the ground using a portable phone who wanted to communicate directly with a satellite in geostationary orbit would need a telephone capable of producing an output in excess of hundreds of Watts. Generating this power output is not only thoroughly impractical for users of portable phones, but may also create a radiation hazard for the individual wielding the telephone.

Brief Summary Text - BSTX (24):

Bertiger, Leopold and Peterson describe a "Satellite Cellular Telephone and Data Communication System" in European Patent Application No. 891 184 58.2. This application sets out some of the details of Motorola's proposed Iridium.TM. communication system. The Iridium.TM. system is currently designed to utilize sixty-six (66) satellites in low Earth orbit which would generate relatively large footprints of radio beams due to their extremely low mask angle of eight and one half degrees (81/2.degree.). Because of these very large footprints, the communications capacity that may be offered by the Motorola network would be substantially constrained. In addition, this system would employ "satellite-fixed cells" which are not defined by any constant boundaries on the Earth. These cells would sweep over vast regions of the Earth at very high speeds as the Iridium.TM. satellites fly overhead. This method of using satellite-

fixed cells introduces extremely complicated "hand-off" problems when
one satellite moves out of range of supplying service with a
subscriber. At that time, another satellite must assume the
responsibility of supporting the subscriber's call without
interruption.

Brief Summary Text - BSTX (31):

The preferred embodiment of the invention comprises a low Earth
orbit satellite system that includes 40 spacecraft traveling in each
of 21 orbital planes at an altitude of 700 km (435 miles). This
relatively large number of satellites in the constellation was
selected to provide continuous coverage of the Earth's surface at a
high minimum mask angle of forty degrees with respect to the Earth's
surface, thus avoiding foliage, terrain, and minimizing the length of
the signal's passage through rain. Each of the individual 840
spacecraft functions as a sovereign switch which knows the position
of its neighbors, and independently handles traffic without ground
control. The satellites are capable of transporting calls to millions
of customers using portable, mobile and fixed residential and
business terminals, and gateways to public phone networks. The
constellation uses the 20 and 30 GHz frequency bands for
communications between Earth and the constellation, and the 60 GHz
band for communicating among the satellites. The use of these
extremely high frequencies allows for the use of relatively low
power, miniaturized antenna components both on the ground and aboard
the satellites. The entire constellation is designed to serve over
twenty million subscribers and 60,000 full time DS-0 (64 kbps)
circuits. The satellites will be coupled to traditional public and
private phone systems on the ground through gateways which each
utilize relatively large antennas and handle large volumes of call
traffic. In the preferred embodiment of the invention, this interface
between the terrestrial systems gateway and the terrestrial network
is based on current standard ISDN interfaces to preserve
compatibility.

Brief Summary Text - BSTX (34):

The present invention also incorporates novel software which runs
on a processor onboard each satellite in the network. Autonomous
Orbit Determination (AOD) algorithms provide each spacecraft with
location information about its own position and the position of every
other satellite in the network. This position information is used to
determine the optimum pathway for routing call traffic among the
satellites in the constellation. These data are also used to maintain
each spacecraft in its proper orbital position, to steer antennas
that receive and transmit signals from neighboring satellites, and
may be used to offer Radio Determination Satellite Service (RDSS)
which is superior to service currently available from the Global
Positioning Systems (GPS) service. One embodiment of the AOD software

employs a ranging algorithm that calculates distances between spacecraft or between spacecraft and ground stations by measuring time delays that are inherent in the radio transmissions conveyed by the network. A second embodiment of the AOD software incorporates an algorithm which fixes spacecraft position by measuring the Doppler shifts of satellite or ground station transmissions. The AOD software also determines the attitude of the spacecraft using data from the antenna steering function. A third embodiment uses signals from known, fixed location ground terminals to determine both satellite location and attitude with great accuracy. Appendix A, which accompanies this specification, contains a complete computer program that embodies the AOD software.

Brief Summary Text - BSTX (35):

The AOD software generates position information that is used by a second computer program that utilizes a novel Adaptive Routing Algorithm (ARA). Like the AOD software, the ARA runs continuously on a processor on board each satellite. The output produced by the AOD program enables the ARA software to monitor the constantly-changing topology of the constellation. The ARA is also responsible for keeping track of the flow of call traffic through the nodes and links of the constellation and to compensate for traffic congestion and node failures. Appendix B, which accompanies this specification, contains a complete computer program that embodies the ARA software.

Drawing Description Text - DRTX (9):

FIG. 7 is a perspective view of a hand-held portable phone. In the preferred embodiment, a hemispherical microwave antenna extends from the body of the phone on a collapsible mast.

Drawing Description Text - DRTX (48):

FIG. 79 is schematic depiction of a low Earth orbit satellite using transmissions of communications packets from a ground station to compute its orbital position.

Drawing Description Text - DRTX (50):

FIG. 81 is a block diagram of position determination circuitry.

Drawing Description Text - DRTX (88):

FIG. 116 is an illustration of the Callingsat.TM. satellite, as it would appear in its fully opened and deployed position in low Earth orbit. This illustration shows how the present invention would be deployed to provide communications links to Earth and to other Callingsats.TM. in its constellation.

Detailed Description Text - DETX (5):

   FIG. 3 presents functional blocks that each provide specialized
signal processing. The components portrayed in FIG. 3 may reside in a
hand-held personal phone (P), a mobile phone (M), fixed phone (F), or
may be located at a gateway (G). Each of these blocks occupies a
particular position along a communications pathway that extends up to
one or more satellites S via an antenna, and then back down through
the antenna to the terminal 30. Although this network 28 is capable
of conveying virtually any form of information, including audio,
video or data signals, FIG. 3 emphasizes a telephone call in which
voices from either end of the call are transmitted through the
network. The user gains access to the network by using the keypad and
display 31 on terminal 30. Tones and text appearing on display 31
that help guide the user through the access procedure are generated
by circuitry in stage 33. Once the call is established, the user's
voice, which is represented in the drawing as an analog voice signal
32, is processed by an Analog-to-Digital "A/D" Converter 34. The
digitized output 36 produced by converter 34 is a stream of ones and
zeroes which are generated at the rate of 64,000 bits per second
(KBIT/sec). The digital signal 36 is then processed by a speech
encoder 38, yielding digital encoded speech 40. To protect telephone
calls from eavesdroppers, the signal is then passed to encryption
equipment 42, which utilizes an encryption key 44 from a signalling
and control processor 46. Encrypted output 48 is then combined with
sequence numbers 50, destination addresses 52, and signal packets 54
generated by processor 46. All these signals are merged together by a
packet assembler 56 that composes packets 58. An error encoder 60
adds information to the packets 58 which enables the packets 58 to be
checked for transmission-induced errors farther downstream. The
packets 58 that are ready to be transported wait in a transmit buffer
62. In the last processing stage associated with the uplink portion
of the journey, packets 58 are forwarded to transmitter 64, which is
coupled to power control circuitry 66 and frame and bit timing
circuitry 68. Finally, radio signals 72 are emitted from an antenna
70 which may be controlled by steering logic circuits 74.

Detailed Description Text - DETX (9):

   FIG. 6 is a schematic diagram that reveals the fundamental
architecture of the present invention. A portion of the network 158
includes satellite nodes 160, which communicate over inter-satellite
links 162. Signals are passed between the orbiting nodes 160 and
gateway interfaces 166 over gateway-satellite links (GSLs) 164. The
gateway interfaces 166 are, in turn, connected to operation support
systems 168, feature processors 170, gateway switches 172 and
database systems 174. As shown schematically in FIG. 6, the network
158 also communicates directly with customers 178 using hand-held
phones and car phones 182 over mobile terminal satellite links
(MTSL's) 176 and 180 that are capable of carrying 16 kilobits of

voice or data signals per second (kbps). Subscribers 186 using fixed
terminal satellite links (FTSL's) 184 will be able to communicate at
the rate of 64 kbps. The apparatus and methods depicted in FIGS. 3,
4, 5 and 6 are explained in greater detail in the sections appearing
below entitled System Communication Links and Call Handling.

Detailed Description Text - DETX (11):

   FIG. 7 illustrates a hand-held portable phone that includes a
Terrestrial Antenna for a Satellite Communication System. In the
preferred embodiment, a hemispherical millimeter wave antenna 210 is
used in conjunction with a portable telephone T that includes an LCD
display screen L, a keypad K, and a battery pack B. In this version
of a compact hand-held transceiver T, the antenna 210 is mounted on a
collapsible mast M, which is shown in both the extended and stowed
positions, EX and ST. FIGS. 8 and 9 exhibit top and side views of the
invention 210A, which incorporates a generally trapezoidal, semi-
conical housing. An inclined exterior surface 212 includes an upper
and a lower portion 212a and 212b. This slanted ring 212 is attached
to both a top circular surface 214 and a bottom circular surface 216.
Both the side and top surfaces 212 and 214 provide support for a
number of generally circular antenna elements 218. The patches 218 on
the side 212 of the antenna 210A form an azimuth array, while those
situated on the top 214 belong to an elevation array. These elements
218 utilize a conductive patch 220 bearing a cross-slot 222 that is
formed from two individual perpendicular slots 222a and 222b. In one
embodiment that is designed for use with the 20 GHz band, the
diameter of the top surface 214 is 1.5 inches (3.8 cm). The side
surface 212 is 1.0 inch (2.5 cm) high, and the bottom surface 216 is
2.5 inches (6.4 cm) wide. The nominal gain of this embodiment is
approximately 20 dB. For the 30 GHz band, the diameter of the
radiating patches shrink to about seventy percent of the larger 20
GHz antenna patch. For a trapezoidal geometry where the ratio of the
bottom 216 and top 214 surfaces is 5/3, beams emanated by this
embodiment are capable of being steered electronically over 360
degrees in the azimuth plane and plus or minus 60 degrees in the
elevation plane. Active and passive microwave components are located
within the housing attached to a ground plane.

Detailed Description Text - DETX (22):

   For optimal performance, the vertical axis of the antenna 210
should point at the zenith, but the beam steering capabilities of the
antenna 210 can overcome the effects of using the transceiver T at
different angles, as long as the signal from the portable phone
remains pointed somewhere within the mask angle. If the orientation
of the antenna 210 presents a problem for the subscriber, the hand-
held unit can be connected to an external antenna which is mounted at
a fixed angle or which is more sensitive. The low power design of the
present invention substantially eliminates any radiation hazards.

Detailed Description Text - DETX (28):

The switching methods disclosed and claimed in this patent
application overcome the limitations encountered by conventional
packet switching using virtual circuits. The fast packet switch
utilizes a "datagram" approach that routes every packet conveyed by
the system independently at every node in the network. The packets
are directed along an optimized pathway through the network by a fast
packet switch that directs traffic based on instructions from a
microprocessor that continuously runs an adaptive routing algorithm.
This microprocessor uses orbital position information generated
aboard each spacecraft to monitor the rapidly changing topology of
the constellation and the distribution of traffic among its nodes and
links. The self-routing fast packet switch works in combination with
an input packet processor, a routing cache memory, and an adaptive
routing processor. The input packet processor functions like a
gatekeeper or guide that extracts the destination node address from
each packet and uses it to access routing information stored in the
routing cache memory. The adaptive routing processor constantly
updates the routing cache memory so each satellite has an accurate
"knowledge" of the whereabouts of all its neighbors, and of the
expected packet delay from adjacent nodes to all possible destination
nodes. Based upon this position and expected delay information, the
adaptive routing processor selects the best pathway from a particular
satellite to a single neighboring satellite, and the packet is then
moved through internal switch circuitry onboard the satellite on its
way to other spacecraft in its journey to some eventual destination
on Earth. The switching methods of the present invention optimize the
utilization of the network facilities and minimizes transmission
delays and variances of transmission delays. By precalculating the
optimal route for each packet one step at a time at each satellite,
the amount of time required to process individual packets is greatly
reduced.

Detailed Description Text - DETX (29):

FIG. 37 is a flow chart 410 that explains the switching process as
it occurs on each satellite S in the constellation C. Orbital
position information 412 is an input to an adaptive routing processor
414 which runs an adaptive routing algorithm (ARA) 416. The ARA 416
constantly monitors the changing locations of all the spacecraft S in
the network, and also keeps track of communications traffic
congestion among the links and nodes of the system. The adaptive
routing processor 414 produces an output called "Next-node-in-path-
to-destination" 418. As the name implies, this output 418 contains
information and provides instructions for moving communications data
through the network one node at a time.

Detailed Description Text - DETX (32):

FIG. 38 presents a block diagram of a satellite switch node 442. One fast packet switch 438 is shown in the upper portion of the diagram, and receives signals from a series of circuit modules 444 and 452. Module 444 includes a receiver 446 coupled to receive antennas (not shown in FIG. 38), a demodulator 448, and a bit/packet synchronizer 450. Module 452 provides input packet control, and comprises circuits for error detection 454, packet tagging 456, local cache access 458 and network cache access 460. The series of input packet control modules 452 are also connected to control complex 462 through a local routing cache 476 and a local routing and handover processor 474. Another link to the input packet control modules 452 are coupled to the control complex 462 through a network routing cache 480 and a network management and routing processor 478. The control complex 462 is an array of circuit stages that include a signalling and call control processor 464, a test and maintenance processor 466, a system control and reload processor 468, a billing and traffic processor 470 and a satellite ephemerides processor 472. The control complex 462 is coupled to a communications processor 482, a spare processor 484 and a beam steering processor 486, which is connected to output packet control modules 490 and 496. Modules 490 comprise circuits that keep track of path history 492 and that are responsible for error encoding 494. Modules 496 include packet framing circuits 498, modulators 500 and transmitters 502 connected to transmit antennas (not shown in FIG. 38).

Detailed Description Text - DETX (37):

Beam compensation pertains to the assignment of individual radio beams from the constellation of satellites to delineated regions on the ground with fixed boundaries called "cells." This beam management system offers enhanced frequency coordination and communication reliability. Beam compensation substantially eliminates the problem of rapid "hand-offs" of a communication channel among the multiple beams of one satellite or between satellites as one satellite moves as one satellite moves out of range of subscribers within the cell and another takes over to supply service to the cell.

Detailed Description Text - DETX (38):

The system allocates the radio beams which are generated by the satellites. These beams are precisely controlled so that they illuminate "Earth-fixed cells" as opposed to "satellite-fixed cells." In previous satellite communication schemes, spacecraft which are not held stationary over one particular location on the Earth in geo-synchronous orbits fly over large regions of the Earth very rapidly. The radio beams generated by these fast moving spacecraft sweep across vast regions of the Earth's surface at the same rate of speed. If these beams were visible to the eye, they would paint bright circular and elliptical patches of light on the ground beneath the satellite which emitted them. In a system that employs satellite-

fixed cells, the "footprint" of the radio beams propagated by the spacecraft defines the zone on the ground called a "cell" which is illuminated by the spacecraft. This satellite-fixed cell moves constantly as the spacecraft moves around the globe. In sharp contrast, an "Earth-fixed cell" is a stationary region mapped onto the surface of the Earth that has permanent fixed boundaries, just like a city or a state. Although the rapidly moving satellites still shine their radio beams over the ground in rapidly moving footprints, the locations of the footprints at any given time do not determine the location of the unchanging Earth-fixed cells. The great advantage provided by using cells having boundaries that are fixed to the Earth is realized when a subscriber being served by one satellite must switch to another beam in the same satellite or to a second satellite because the first is moving out of range below the local horizon. With satellite-fixed cells, this "handover" involves the assignment to the terminal of a new communication channel within the new beam or new satellite. This assignment process takes time and consumes processing capacity at both the terminal and the satellite. It is also subject to blocking, call interruption, and call dropping if there is not an idle communication channel in the next serving beam or satellite. The Earth-fixed cell method avoids these problems by allocating communication channels (frequency, code, and/or time slot) on an Earth-fixed cell basis rather than on a satellite-fixed cell basis. Regardless of which satellite/beam is currently serving a particular cell, the terminal maintains the same channel assignment, thus eliminating the "handover" problem.

Detailed Description Text - DETX (43):

    FIG. 48 is a flow chart 618 which discloses one implementation of the preferred embodiment of beam compensation. A packet 422 is shown as it progresses through mapping and switching hardware which directs the packet 422 to the beam which is currently serving the Earth-fixed supercell 604 and cell 606 in which the destination terminal 619 resides. The incoming packet 422 possesses "node" 620 and "call identification (ID)" 622 bits that comprise a terrestrial location identification about the terminal where the call originated. The substance of the phone call, such as voice or video information, has been digitized and is carried as the payload portion 426 of the packet 422. The node 620 identifies the satellite S currently serving the destination terminal 619. The call ID 622 is used as an input to a cell ID map 624, which is used as a translation device for a fast packet switch 438 that actually selects the beam B that will be used to deliver the payload 426. The call ID map 624 identifies the supercell 604, cell 606, and channel 626 assigned to the destination terminal 619 within this node 620 as identified by the call ID 622 in the incoming packet 422. In the present context, a channel 626 is a portion of beam B that has been allocated into several frequencies. Output beams are recorded in a position/output beam map 630. The satellite beam B which is currently assigned to serve a particular

supercell 604 is also a function of the instantaneous position of the satellite S which is generating beams B to handle a given call. This position information is produced by autonomous orbit position determination software 628. Once the channel 626, cell 606, and beam assignments have been derived, these assignments are appended to the payload 426 of the packet 422, replacing the call ID 622. After mapping, the modified packet 632 is then transmitted to the fast packet switch 438, which uses this information to direct the packet 422 to the appropriate buffer slot in the beam B currently serving this supercell 604. The transmission system determines the frequency that will be used for the transmission of the packet 422 based on the selected channel, and picks the time slot for transmission based on the selected cell 606. In the original embodiment of the beam compensation invention, the time slot is 1.444 milliseconds in duration, and the frequency domain modulation (FDM) cycle for the beams is 23.111 milliseconds long. The time required for communication is 1.156 milliseconds, and 0.289 milliseconds of guard time is provided. The receive beams lag the transmit beams by twice the time encountered by the transit delay between the user and the satellite. This lag time varies from 6.8 milliseconds for supercells at the edge of the footprint to 4.7 milliseconds for supercells directly below the satellite. The variation over a supercell 604 ranges from 0.04 milliseconds for cells 606 directly below the satellite to 0.7 milliseconds for cells 606 at the edge of the footprint.

Detailed Description Text - DETX (44):

The beams B generated by antenna facets (not shown in FIG. 48, but shown below in FIGS. 49 and 50) on the satellites S include 256 transmit and 256 receive scanning beams. The satellites travel at an orbital height of 700 km and service cells within a 40 degree terminal elevation mask angle footprint. The satellite footprint 602 measures approximately 1.6 million square kilometers. The satellite antenna beams B that service cells 606 directly below the satellite S have a gain of 37.7 dB and half power beamwidths of 2.6 degrees. The beams B that service cells 606 at the edge of the satellite footprint 602 have a gain of 40 dB and half power beamwidth of 1.8 degrees. The beams illuminate circular spots on the Earth's surface of approximately 800 square kilometers. The square inscribed within this circular spot has an area of 512 square kilometers (22.6 km sides). This geometry provides 1.84 km (13%) of overlap at the cell corners. The overlap 615 mitigates the effects of satellite position errors and beam pointing errors. The tolerable error limits are 300 meters maximum for satellite position determination error and 1.5 km (0.17 degree) maximum for beam pointing errors. The movement of the beam footprint 602 on the Earth's surface due to the motion of the satellite S is less than 12 meters over the 1.444 millisecond dwell time, and less than 200 meters during the 23.111 millisecond supercell timing cycle. Instead of computing the required pointing

angles for each spot beam every 1.444 milliseconds, the pointing angles for the center of the supercell may be computed every 23.111 milliseconds, and the beam B is then positioned relative to this center for each cell. The rotation of the Earth contributes an error to this computation, but is less than 6% of the effect of satellite motion, and the same method can be used to compensate for this motion. The same method can also be used to compensate for satellite attitude motion (roll, pitch, and yaw). When a supercell 604 is contained within the footprints 602 of two or more satellites, then the satellites S negotiate among themselves as to which ones will service that supercell 604. One satellite may be assigned complete responsibility or the frequency allocation may be divided among several satellites. Each cell 606 is designed to provide service for up to 720 16-kilobit per second subscribers using portable terminals, and 360 terminals operating at 64-kilobits per second.

Detailed Description Text - DETX (45):

The beam compensation invention described above offers several advantages over previous beam allocation systems. Terminals are served by the footprint 602 of the satellite that happens to be passing overhead at the time a particular call flows through a given terminal. By allocating the beams to Earth-fixed cells as opposed to satellite-fixed cells, the problem of performing frequent "hand-offs" from satellite to satellite is substantially eliminated, since a terminal keeps the same frequency (channel) and time slot (cell) for the duration of the call even though it communicates via different beams and satellites during the call. A similar system using satellite-fixed cells with each satellite footprint partitioned into approximately four thousand cells would require a cell hand-off approximately every five seconds. The utilization of the beam compensation invention described above requires these undesirable hand-offs only when a subscriber using a portable P or mobile M terminal actually transits across a cell boundary. The Earth-fixed cell method also avoids the danger of accidentally terminating a call if all of the channels in the cell to which the beams are switched are already occupied. The allocation method of the present invention that switches a call from the beams of one satellite to another is completely transparent to the customer. The Earth-fixed cell technique also offers enormous spectral efficiency, since 100% of the frequencies between the cells and between the satellites are constantly reused. Similar systems using satellite-fixed cells often divide the assigned frequencies into bands assigned to satellites to avoid frequency conflicts, but that procedure is an inefficient use of the valuable frequency spectrum.

Detailed Description Text - DETX (61):

The spaceborne antennas 702 are capable of providing a gain of 45 dB at the periphery of each footprint and 42 dB at the nadir

<u>position</u>. Because the beams generated by the spaceborne antennas 702 are so powerful, Earth-based terminals can incorporate low power antenna designs which substantially eliminate any radiation hazards that might otherwise harm the user. Each antenna uses a combination of the 20 and 30 GHz frequency bands for satellite to ground communications, and propagates 256 simultaneous beams, which are multiplexed to 4,096 positions. Beams aimed at the horizon possess an elliptical, as opposed to a circular or polygonal, shape to compensate for the low grazing angle, so that a constant Earth coverage footprint is maintained. Uncorrected beams have an elliptical ground pattern which degrades spectral reuse efficiency. Electronic beam steering also permits the independent control of directivity gain and power gain. The beam steering provides a convenient method of correcting power levels during rain fades. The transmitted power gain from the satellite can be increased on transmit to overcome downlink fading. Satellite receive power gain can be increased during receive to overcome uplink fading. The use of these two techniques overcomes possibly poor communication performance during rainy weather conditions.

Detailed Description Text - DETX (66):

Every satellite S controls the assignment of channels to terminals requesting services. When a terminal has more than one satellite in view, the satellites monitor the signal quality and select which one is best suited to handle the call to the terminal. The receive beam from the ground terminal lags the transmit beam emitted from the satellite by a fixed interval. The terminal transmits its data to the satellite at a delay specified by the satellite in its preceding scan. This method is used to compensate for delay differences caused by variations in path lengths. The scan pattern among beams is coordinated to insure that all cells being scanned at one instant are separated by sufficient distance to eliminate interference among many closely-spaced customers. An electronic pushbroom carries the beams through one beam <u>position</u> in the direction of satellite travel, and then performs a flyback. Each beam carries a pilot tone which identifies each beam for terrestrial terminals. Components on board each satellite measure time delay and Doppler shift of each subscriber signal to determine the location of the subscriber within a particular beam footprint. Because the satellite antennas operate at a relatively high gain, the footprints on the ground are relatively small. Since the cells are small and the satellite footprint moves rapidly over the Earth's surface, any particular terminal remains in the same cell for only a few seconds. To avoid the rapid <u>handoff</u> from satellite to satellite every few seconds, the innovative logical/physical cell mapping scheme described above as Beam Compensation is utilized in conjunction with the present invention.

Detailed Description Text - DETX (80):

At any given time, three of the sixty antenna panels 814 are pointed toward the Earth's surface and are transmitting and receiving signals. As the satellite 810 revolves, antenna panels 814 become active as they move into position facing the Earth E, and also terminate their activity as they turn away from the Earth. This continuous hand-off of the communication operation from one set of antenna panels 814 to another is controlled by Earth sensors, and insures that radio beams B from the satellite 810 are always illuminating the footprints 602 on the surface. The Gearsat.TM. embodiment 810 derives its name from the spatial synchronization of the antenna panels 814 with specific regions of the ground that are illuminated by the beams generated by the antennas. Like the engaged teeth of two mechanical gears, particular antenna panels 814 in the array are matched with particular regions on the ground. Radio beams B emanating from the sixty panels 814 are essentially "locked" or dedicated to specific footprints 602 or cells below it on the Earth's surface. While the text above specifies one particular satellite configuration that offers this form of spatial synchronization among antennas 814 and beam footprints 602, the reader will appreciate that the central objective of providing a dedicated relationship among many antennas and footprints may be carried out using a wide variety of various implementations without departing from the spirit and scope of the invention claimed below. For example, an alternative embodiment of Gearsat.TM. could simply wobble, rock or nutate periodically to provide a partial rotation motion that would direct antennas beams across predetermined regions on the ground. The Gearsat.TM. motion need not be a complete rotation through 360 degrees of arc. Any spatial synchronization of moving antennas which maps antenna beams to particular areas on the Earth's surface would implement the Gearsat.TM. invention.

Detailed Description Text - DETX (83):

The diagram 818 shown in FIG. 68 reveals subsystems that provide Electrical Power 826; Attitude and Orbit Determination and Control 828; Propulsion 834; and Command and Data Handling 824. Each of these subsystems are connected to a bus 820 that is also coupled to a Communications Payload Subsystem 822, which includes the fast packet switch 438 and its related circuitry. The Electrical Power Subsystem 826 (EPS) derives energy from the photovoltaic cells covering panels 704 (solar arrays S/A), and power is stored in nickel metal-hydride batteries. The Attitude and Orbit Determination and Control Subsystem (AODC) 828 maintains the orientation of the spacecraft using three axis stabilization methods. Actuators (ACTRS) 832 are employed to perform the stabilization process. Sun sensors 830 are used as an initial reference once the satellite achieves orbit. Afterwards, inertial measuring units, magnetometers, and information gathered from call traffic is used to keep the craft on course and steady in its desired position. Each satellite "knows" its own position and the positions of all the other satellites in the constellation, as well

as all the positions of terminals on the ground. A Propulsion
Subsystem 834 uses redundant pulse-plasma thrusters which accomplish
maneuvers that include orbit insertion, drag make-up, stationkeeping
and deorbit at the end of the satellites lifetime. A Command and Data
Handling Subsystem (C&DH) 824 acquires, conditions and formats all
satellite data and decodes, stores and distributes all satellite
commands. The C&DH 824 comprises a processor with a 4 Gb solid-state
RAM memory that is coupled to a local area network (LAN). A
microprocessor analyzes, interprets and compresses on-board data, and
another microprocessor, running at 20 million instructions per second
(MIPS), is dedicated to processing traffic. A Cabling Subsystem 836
contains all the conductors that unite the power and signal
electronics on the ship. A Structure Subsystem 838 comprises the
geodesic, concave, stackable support skeleton which bears the antenna
array 700. A Mechanisms Subsystem 840 includes components that deploy
and orient the solar panels 704. A Thermal Control Subsystem 842
includes blankets and coats of paint that manage the thermal
conditions of the satellite S.

Detailed Description Text - DETX (97):

   The values presented below the column labeled "Elevation" are
angles measured in degrees with respect to the direction of the
Nadir. The values presented below the column labeled "Azimuth" are
angles measured in degrees with respect to the direction of the
Velocity Vector 802, as shown in FIGS. 77 and 78.

Detailed Description Text - DETX (98):

   Each of the embodiments of the invention, Domesat.TM.,
Gearsat.TM., Batsat.TM. and Callingsat.TM. may incorporate teflon
thrusters for precise altitude, attitude and position control. These
thrusters use small pieces of a material such as teflon as fuel.
Extremely small amounts of the teflon are expelled from miniature
nozzles, and the slight reactions of the spacecraft provide highly
precise position control.

Detailed Description Text - DETX (124):

   Spacecraft Position and Attitude Determination

Detailed Description Text - DETX (125):

   Each spacecraft in the constellation requires orbital position
information about itself and other satellites in the constellation.
Each satellite carries a navigation computer which 1000 that depicts
a satellite S in low Earth orbit. The satellite is capable of routing
communication signals or telephone calls carrying voice, data, and
video signals among ground stations 1006 and 1008 and other

satellites 1002. The AOD software is used to calculate position information accurate to within 10 km for a constellation of 840 satellites S orbiting at 700 km (435 miles). Although the preferred embodiment employs an orbital altitude of 700 km, the invention may utilize an altitude of from approximately 525 km to approximately 1400 km. The population of the constellation may include one hundred or more satellites, which are deployed in at least eight orbital planes. In the preferred embodiment of the invention, each of the orbital planes is inclined to the equator at an angle of 98.2 degrees. This inclination angle may, however, vary from 65 to 125 degrees. The eccentricity of the orbits may extend from 0.001 to 0.005. A complete listing of the computer software that embodies the AOD software is contained in Appendix A. This software runs on a conventional IBM compatible personal computer and simulates orbital position determination for selected embodiments of the present invention. This software enables a person skilled in the art to which the AOD software pertains to practice this portion of the invention without undue experimentation.

Detailed Description Text - DETX (126):

The packets 422 that are transmitted and received by the satellites S include headers 424 which hold address information that enables switching circuitry 438 aboard each spacecraft to route the packet to its proper destination. The header 424 includes time and frequency information that is used by a microprocessor called an orbit determination processor aboard each satellite to generate an inter-satellite almanac packet. Unlike communications packets 422 which are constantly relayed among spacecraft in the system to their final destinations on the ground, inter-satellite almanac packets are broadcast among the entire constellation at least once every day. These inter-satellite packets contain an almanac message that contains information which is used to calculate orbital position.

Detailed Description Text - DETX (129):

FIG. 81 is a block diagram that reveals details of position determination circuitry 1026. A communication link 1028 conveys information to a demodulation stage 1030, which forwards information about the time of perception of packets 1040 to a time and frequency synchronization stage 1042. A frequency synthesizer 1032 is coupled to the data demodulation stage 1030 and to a phase locked loop stage 1036. The frequency synthesizer 1032 is also coupled to an oscillator 1034. The phase locked loop stage 1036 and an antenna control stage 1024 receive pilot tones 1038 as inputs. The phase locked loop stage 1036 measures Doppler shifts 1044, while the antenna control stage 1024 determines correct antenna pointing directions 1048. The Doppler measurements 1044 serve as inputs to an autonomous orbit determination processor 1046. The pointing directions 1048 are used for attitude determination 1050.

Detailed Description Text - DETX (130):

FIG. 82 is a schematic diagram 1052 showing a satellite S in orbit communicating with a gateway G. The figure illustrates the calculation of attitude information computed by the spacecraft. The AOD methods not only provide <u>position</u> information which is used to select optimal pathways for routing communications traffic, but also supplies output that is utilized for spacecraft guidance and control and inter-satellite antenna steering and generates pseudo-ranging packets for highly accurate radio determination satellite service (RDSS). The AOD software incorporated in the preferred embodiment is presented in Appendix A. This program autonomously determines the <u>position</u> of each satellite in the constellation on board each satellite, as well as the <u>position</u> of all the other satellites in the constellation. The software also autonomously provides altitude and attitude information for each satellite.

Detailed Description Text - DETX (132):

Switching circuits about each satellite in the constellation transport packets of data through a low Earth orbit satellite network. Each satellite furnishes intelligent and autonomous on-board switching capabilities and provides synchronous, circuit-switched communication services with uniform end-to-end transmission delays. The routing methods implemented on the switching hardware manage the satellite communication links between the origin and destination of telephone calls which convey voice, data, or video information. The spaceborne switches are capable of selecting the best series of connections from a terrestrial gateway or terminal up through a satellite constellation and back down to Earth. The pathway that is selected for a particular call must be highly adaptive and able to change rapidly in response to the constantly changing geometry of the low Earth orbit constellation. Based upon inputs from the position determination algorithms that define the length of each link in the system, the methods implemented by the present invention determine the optimal route for each transmission from each satellite and also establishes the most efficient distribution pattern of traffic throughout the system.

Detailed Description Text - DETX (134):

The traffic routing switches overcome the limitations encountered by conventional packet switching using virtual circuits. The present invention utilizes a "datagram" approach that routes every packet conveyed by the system independently at every node in the network. The packets are directed along an optimized pathway through the network by a fast packet switch that directs traffic based on instructions from a microprocessor that continuously runs an adaptive routing algorithm. This microprocessor uses orbital position information generated aboard each spacecraft to monitor the rapidly

changing topology of the constellation and the distribution of
traffic among its nodes and links.

Detailed Description Text - DETX (135):

In general, the hardware that is responsible for traffic routing
comprises a self-routing fast packet switch, an input packet
processor, a routing cache memory, and an adaptive routing processor.
The input packet processor functions like a gatekeeper or guide that
extracts the destination node address from each packet and uses it to
access routing information stored in the routing cache memory. The
adaptive routing processor constantly updates the routing cache
memory so each satellite has an accurate "knowledge" of the
whereabouts of all its neighbors, and of the expected packet delay
from adjacent nodes to all possible destination nodes. Based upon
this position and expected delay information, the adaptive routing
processor selects the best pathway from a particular satellite to a
single neighboring satellite, and the packet is then moved through
internal switch circuitry onboard the satellite on its way to other
spacecraft in its journey to some eventual destination on Earth. The
present invention optimizes the utilization of the network facilities
and minimizes transmission delays and variances of transmission
delays. By precalculating the optimal route for each packet one step
at a time at each satellite, the amount of time required to process
individual packets is greatly reduced.

Detailed Description Text - DETX (139):

The satellite altitude is fixed at 700 km (435 miles). The
relatively large number of satellites in the preferred embodiment of
the constellation has been selected to provide continuous coverage of
the Earth's surface at high angles of radiation with respect to the
Earth's surface, thus avoiding foliage, terrain, and minimizing the
length of the signal's passage through rain. Each of the individual
336 spacecraft functions as a sovereign switch which knows the
position of its neighbors, and independently handles traffic without
ground control. The satellites are capable of transporting calls to
millions of customers using portable mobile and fixed residential and
business terminals, and gateways to public phone networks. The
constellation uses the 20 and 30 GHz frequency bands for
communications between Earth and the constellation, and the 60 GHz
band for communicating among the satellites. The use of these
extremely high frequencies allows for the use of relatively low
power, miniaturized antenna components both on the ground and aboard
the satellites. The entire constellation is designed to serve over
twenty million subscribers and 60,000 full time DS-0 (64kbps)
circuits. The satellites will be coupled to traditional public and
private phone systems on the ground through gateways which each
utilize relatively large antennas and handle large volumes of call
traffic. In the preferred embodiment of the invention, this interface

between the terrestrial systems gateway and the terrestrial network
is based on current standard ISDN interfaces to preserve
compatibility. Unlike presently available cellular systems which
relay calls to subscribers from local radio towers, the present
invention offers direct communication between the satellites of the
constellation and individuals using lightweight portable mobile and
fixed telephones.

Detailed Description Text - DETX (140):

One of the important inputs to the fast packet switch circuitry is
a continuous stream of orbital <u>position</u> information which is
generated aboard each satellite by a navigation computer running
Autonomous Orbit Determination algorithms (AOD). The AODs compute
ephemeris parameters for each satellite. These parameters are
broadcast to every satellite in the constellation, so that all the
spacecraft "know" their own positions and the position of every other
satellite in the network. One embodiment of the AOD algorithms
employs an inter-satellite ranging algorithm that calculates
distances between spacecraft by measuring time delays that are
inherent in fast-packet switching transmissions. A second embodiment
of the AOD software incorporates an algorithm which fixes spacecraft
<u>position</u> by computing differences in Doppler shifts of satellite
transmissions. A third version uses known location fixed Earth
reference stations to determine <u>position</u>. Once the orbital position
information is generated, it is used as an input to an adaptive
routing processor which runs an adaptive routing algorithm (ARA). The
ARA constantly monitors the changing locations of all the spacecraft
in the network, and also keeps track of communications traffic
congestion among the links and nodes of the system. The adaptive
routing processor produces an output called "Next-node-in-path-to-
destination". As the name implies, this output contains information
and provides instructions for moving communications data through the
network one node at a time.

Detailed Description Text - DETX (216):

Packets 422 are received from mobile and fixed terminals located
under the satellite footprint via <u>Mobile Terminal-Satellite Links
(MTSLs) and Fixed Terminal-Satellite Links</u> (FTSLs); gateways used for
<u>bringing in traffic from calls</u> originating or terminating on the
<u>public network</u> via Gateway to Satellite Links (GSLs); and other
satellites via the InterSatellite Links (ISLs). Packets 422 are
grouped in two categories, those carrying user data comprising voice,
video, digital data, etc.; and those carrying control messages that
are used in network administration and control functions. The Fast
Packet Switch (FPS) is responsible for switching each incoming packet
to its appropriate destination. Packets can be switched to
satellites, gateways and terminals. Those destined for other
satellites are transported over ISL output links. Packets passing

through satellite nodes on their way to their final destinations may
contain user data or control messages. Packets directed to a gateway
using a GSL output link may also carry user data or control messages.
If the packet type is user data, the call associated with the packet
originates or terminates on the public network. If the packet conveys
a control message, it terminates at the gateway node common control.
Mobile and fixed terminals can communicate directly with satellites
in orbit. Mobile terminal to satellite links can convey packets at
16Kb per second. Two Kb of the 16Kb MTSL capacity is reserved for a 2
Kb data channel. Fixed terminal to satellite links are 64Kb channels,
of which 8Kb is reserved for data. Packets traveling to mobile and
fixed terminals include user data packets that carry voice messages,
and control message packets bearing call control information. Packets
may also be delivered to a node Message Transport System (MTS) if the
packet type is a control message.

Detailed Description Text - DETX (232):

    In sharp contrast, an "Earth-fixed cell" is a stationary region
mapped to an "Earth-fixed grid" that has permanent fixed boundaries,
just like a city or a state. Although the rapidly moving satellites
still shine their radio beams over the ground in rapidly moving
footprints, the locations of the footprints at any given time do not
determine the location of the unchanging Earth-fixed cells. The great
advantage provided by using cells having boundaries that are fixed
with respect to an Earth-fixed grid is realized when a subscriber
being served by one satellite must switch to another beam in the same
satellite or to a second satellite because the first is moving out of
range below the local horizon. With satellite-fixed cells, this
"hand-off" involves the assignment to the terminal of a new
communication channel within the new beam or new satellite.

Detailed Description Text - DETX (233):

    This assignment process takes time and consumes processing
capacity at both the terminal and the satellite. It is also subject
to blocking, call interruption, and call dropping if there is not an
idle communication channel in the next serving beam or satellite. The
Earth-fixed cell method avoids these problems by allocating
communication channels (frequency, code, and/or time slot) on an
Earth-fixed cell basis rather than on a satellite-fixed cell basis.
Regardless of which satellite/beam is currently serving a particular
cell, the terminal maintains the same channel assignment, thus
substantially eliminating the "hand-off" problem.

Detailed Description Text - DETX (234):

    The present invention uses software that provides position and
attitude information about each satellite in the constellation. The
Earth's surface is initially mapped into an unchanging "Earth-fixed

grid" which each satellite can accurately locate from its position data. Each satellite is capable of steering, transmitting and receiving beams conveying packets of information to the Earth-fixed grid. The beams are continually adjusted to compensate the effects of satellite motion, attitude changes, and the rotation of the Earth. In accordance with the preferred embodiment of the invention, each spacecraft possesses the following capabilities:

Detailed Description Text - DETX (237):

to map from destination cell to the beam currently serving the cell;

Detailed Description Text - DETX (238):

to switch packets to the beam currently serving the destination cell;

Detailed Description Text - DETX (239):

to "hand-off" a terminal from one beam to the next or from one satellite to the next without changing the channel assignment of the terminal; and

Detailed Description Text - DETX (243):

FIG. 105 is a schematic diagram 1210 which illustrates twenty-one orbits 1211 which enclose the Earth E. In the preferred embodiment of the invention, each orbital plane contains forty active satellites 1212 spaced evenly around the orbit 1211, along with up to four spares. The constellation of satellites is designed so that a subscriber's terminal can "see" two or more satellites most of the time. This gives the terminal some protection against shadowing by terrain, allows load sharing among satellites, and also provides redundant coverage in the event of satellite failure. In the specification and claims which follow, the word "terminal" is used to identify portable terminals P like hand-held phones, mobile terminals M such as those mounted in vehicles and fixed terminals F like a permanently installed phone that is available for public use. These terminals are different from gateways G which are generally large terrestrial receiving stations that connect the constellation with public switched networks.

Detailed Description Text - DETX (245):

When the constellation is deployed, each launch vehicle carries a number of satellites. These satellites 1212 are released in their proper orbit plane 1211, and each satellite then adjusts its position within the plane. Onboard thrusters and an autonomous navigation

system continuously monitor and adjust the satellite's altitude, attitude, and position within the orbit plane. A number of spare satellites are placed in orbit along with the first launch of active satellites.

Detailed Description Text - DETX (246):

For a satellite in low Earth orbit, the satellite footprint sweeps over the Earth's surface at approximately 25,000 Km/hr. If the cell pattern of the present invention moved with the satellite footprint, a terminal would remain in one cell for only a few seconds before a channel reassignment or "hand-off" to the next cell is required. As is the case with terrestrial cellular systems, frequent hand-offs result in inefficient channel utilization, high processing costs, and lower system capacity.

Detailed Description Text - DETX (247):

FIGS. 107a and 107b illustrate the preferred embodiment of the invention which substantially eliminates the "hand-off" and frequency coordination problems associated with LEO networks that utilize satellite-fixed cells. FIG. 107a is a view 1218 that reveals the incidence of radio beams from a satellite 1212 that form a footprint 1216 over California. FIG. 107b is a diagram 1222 that depicts the relationships among the Earth-fixed grid 1220, a supercell 1224 and the nine cells 1226 within the supercell 1224. FIG. 107a shows an Earth-fixed grid 1220 of supercells 1224 covering the continental United States.

Detailed Description Text - DETX (248):

In the preferred embodiment, the Earth's surface is mapped into this Earth-fixed grid 1220, which comprises approximately 20,000 "supercells" 1224. Each supercell 1224 contains nine cells 1226. Each supercell is a square 160 km on each side, while each cell 1226 is a square measuring 53.3 km on each side. The supercells 1224 are arranged in bands that are parallel to the Equator. There are approximately 250 supercells 1224 in the band at the Equator, and the number per band decreases in proportion to the cosine of the latitude of their location on the globe. Because the number of supercells per band is not constant, the "north-south" supercell borders in adjacent bands are not aligned. A fixed algorithmic relation defines the mapping between supercell coordinates and latitude-longitude coordinates. A "time-of-day" relation defines which orbital plane has primary coverage responsibility for each supercell 1224, and the satellites' orbital position completes the "Earth-coordinates-to-serving-satellite " relation. This relation makes it possible to determine at any time which satellite has primary coverage responsibility for a terminal based on the terminal location.

Detailed Description Text - DETX (250):

Each footprint 1216 encompasses a maximum of 64 supercells, or 576 cells. The actual number of cells 1226 for which a satellite is responsible is a variable that depends on satellite location and spacing between satellites. As a satellite passes over, it steers its antenna beams to the fixed cell locations within its footprint. This beam steering compensates for the satellite's motion as well as for the Earth's rotation. As an analogous example, the beam steering method employed by each satellite to track a cell as the satellite flies overhead is similar to the motion of the tread of a bulldozer over the ground. Each spot on the tread remains in contact with a single point on the ground while the bulldozer moves along. Frequencies and time slots are associated with each cell and are managed by the current "serving" satellite. As long as a terminal remains within the cell, it maintains the same channel assignment for the duration of a call, regardless of how many satellites and beams are involved. Channel reassignments become the exception rather than the normal case, thus eliminating much of the frequency coordination and hand-off overhead.

Detailed Description Text - DETX (253):

The satellite footprint 1216 comprises a collection of contiguous cells 1226, and is somewhat analogous to a terrestrial cellular system. Each cell 1226 supports a number of communication channels. Terminals within the cell 1226 share these channels using a combination of multiple-access methods that are described in more detail below. Cells are arranged in a pattern which allows frequencies and time slots to be reused many times within a satellite footprint 1216 without interference between adjacent cells 1226. The high gain satellite antennas that will be employed by the preferred embodiment produce small cells (53.3 Km on each side) which result in extremely efficient use of spectrum, high channel density and low power requirements.

Detailed Description Text - DETX (255):

FIG. 111a is a schematic diagram 1258 that shows a single satellite 1212 flying over a target Earth-fixed cell 1226t in three sequential positions. At each of the three positions marked Time 1 (T1), Time 2 (T2) and Time 3 (T3), the satellite 1212 steers beams 1219 to a subscriber in a target Earth-fixed cell 1226t using a mobile, portable or fixed terminal or a gateway which communicate with the satellite using a frequency channel that does not change.

Detailed Description Text - DETX (258):

FIGS. 111d, 111e and 111f are simplified views of a hand-off

process utilized by the present invention. In each of these three views, two satellites employed by the present invention 1212a and 1212b flying in the same orbit 1211 use three antenna elements like those shown in FIG. 111c to direct packets Pk to subscribers on the ground in a <u>target Earth-fixed</u> cell 1226t. Each packet Pk carries a header and a message "payload" 1274. The header includes address information comprising a "destination node" 1270 and a "call ID" 1272. In each of these three drawings, incoming packets Pk have been routed through the network to satellites 1212a or 1212b on their way to subscribers located in cell 1226t using terminals T1 and T2. In this example, these terminals do not change positions, and therefore, remain in the same Earth-fixed cell 1226t, which is also identified as C4.

Detailed Description Text - DETX (259):

FIG. 111d is a "snapshot" of satellites 1212a and 1212b at time 1a. FIGS. 111e and 111f are similar snapshots of the same satellites, but at slightly later successive times 2a and 2b. In FIG. 111d, beams 1219b from the central antenna element 1213b of satellite 12a provide service to fixed location terminals T1 and T2 in target cell 1226t (C4). At slightly later time 2a which is pictured in FIG. 111e, satellite 12a has moved farther away from the terminals in target <u>cell</u> 1226t, but the electronic beam steering circuits aboard satellite 1212a have switched the service to the same terminals T1 and T2 to a different antenna panel 1213c. This "antenna-to-antenna" <u>hand-off</u> is completely undetected by the subscribers using terminals T1 and T2, who continue to enjoy uninterrupted service via beam 1219c without changing their assigned communication channel. At an even later time 3a, which is frozen in the view offered by FIG. 114f, satellite 1212a has moved out of range of the unmoving cell C4 in which terminals T1 and T2 are located. Before satellite 1212a is no longer capable of servicing T1 and T2, the satellites 1212a and 1212b cooperatively <u>hand-off</u> responsibility for continuing the supply of packets Pk to these subscribers, and 1212b assumes control of the call traffic to T1 and T2 using its own antenna panel 1213a and its own beam 1219a. Since T1 and T2 remain within their original cell 1226t, they maintain the same channel assignment, unlike the rapid hand-offs that would be required if satellite-fixed cells were involved. The simplification of the hand-off process results from the fact that terminals stay in the same cell even though the satellites move. Communication resources are allocated on a cell by cell basis.

Detailed Description Text - DETX (260):

The specific algorithm that is employed by the preferred embodiment of the invention involves measuring and comparing the distances between the first satellite 1212a that is serving a target <u>Earth-fixed cell</u> 1226t at a given time, and the distance between a second next satellite 1212b and the target cell 1226t. When the

distance between the centroid of the target cell 1226t to the second
next satellite 1212b is less than the distance from the same centroid
to the first satellite 1212a, the satellite-to-satellite hand-off
occurs.

Detailed Description Text - DETX (261):

In stark contrast, FIGS. 111g, 111h and 111i reveal the
deleterious consequences of furnishing the same service to two fixed
location terminals T1 and T2 using a communication system that
employs satellite-fixed cells, instead of the Earth-fixed cells
scenario pictured in FIGS. 111d, 111e and 111f. Satellites 1261a and
1261b are shown in orbits 1211' communicating with terminals T1 and
T2 via beams 1264 at successive times 1b, 2b and 3b. In FIG. 111g, T1
and T2 are illuminated by cell C2 of satellite 1261a at time 1b. In
this system, however, the cells move along with the satellites 1261a
and 1261b, and continually sweep over the Earth's surface. As shown
in FIG. 111h, at time 2b, T1 and T2 are no longer in cell C2 of
satellite 1261a. At time 2b, T1 is in cell C3 of satellite 1261a and
T2 occupies cell C4 of satellite 1261a. As a result of the motion of
the cells, which each employ different frequencies to avoid signal
interference, satellite 1261a had to change the channel assignment
for T1 when cell C2 moved past it and cell C3 moved over it. FIG.
111h shows that, on some occasions, two relatively close terminals T1
and T2 may be served by different cells. FIG. 111i reveals the
situation at time 3b. Satellite 1261a has moved completely out of
range of T1 and T2, and cell C2 of satellite 1261b has assumed
responsibility for the delivery of packets Pk to the subscribers.
FIGS. 111g, 111h and 111i exhibit the extremely complex hand-off
scheme that must be used by a network using satellite-fixed cells.
Each time a terminal is passed from one cell to the next it must be
assigned a new communication channel (frequency). These very frequent
hand-offs can result in irritating noise during a call, and, in the
worst case, a complete drop-out of the call.

Detailed Description Text - DETX (262):

FIG. 112a is a schematic block diagram 1268 which discloses a
hardware implementation of the preferred embodiment. An incoming
packet Pk is shown as it progresses through mapping and switching
hardware which directs the packet Pk to the Earth-fixed cell beam
1219 which is currently serving the Earth-fixed supercell 1224 and
cell 1226 in which the destination terminal resides. The incoming
packet Pk possesses node and call ID bits 1270 and 1272 that comprise
a terrestrial location identification I about the terminal where the
call originated. The substance of the phone call, such as voice or
video information, has been digitized and is carried as the payload
portion 1274 of each packet. The node 1270 identifies the satellite
1212 currently serving the destination terminal. The call ID 1272 is
used as an index 1276 to a cell ID map 1278, which is used as a

translation device that is upstream from a fast packet switch 1302
that actually selects the Earth-fixed cell beam 1219 that will be
used to deliver the payload 1274. The cell ID map 1278 identifies the
supercell entry 1286, cell entry 1284, and channel entry 1282
assigned to the destination terminal within this node 1270 as
identified by the call ID 1272 in the incoming packet Pk. In the
present context, a channel entry 1282 is a portion of beam that has
been allocated into several frequencies. The satellite beam which is
currently assigned to serve a particular supercell entry 1286 is also
a function of the instantaneous <u>position</u> of the satellite which is
generating Earth-fixed cell beams 1219 to handle a given call. This
<u>position</u> information is produced by an autonomous orbit determination
(AOD) algorithm 1288. The output of the cell ID map 1278 is a
supercell entry 1286, which is used as an index to a position/output
beam map 1290 that, in turn, selects an output beam 1292. Once the
channel 1294, cell 1296, and output beam assignments 1298 have been
derived, these assignments are appended to the payload 1274 of the
packet Pk, replacing the call ID 1272. The packet Pk is then
forwarded to the fast packet switch 1302 through input 1300, which
uses this information to direct the packet to an output 1304 to a
packet buffer 1309. Within this buffer 1309, the packet is directed
to the appropriate slot in the Earth-fixed cell beam 1219 currently
serving a particular supercell. After the packet emerges from the
switch 1302, it carries a channel designation 1306 that specifies
some combination of time slot, frequency, coding scheme or terminal
identifier, as well as a cell designation 1308 that specifies a time
interval. The transmitter 1310 determines the frequency that will be
used for the transmission of the packet based on the selected
channel, and picks the time slot for transmission based on the
selected cell. FIG. 112b furnishes another schematic block diagram
1311 which may be utilized to implement the present invention.

Detailed Description Text - DETX (271):

     FIG. 116 is an illustration of the Callingsat.TM. 1410 shown as it
would appear in its fully opened and deployed position in low Earth
orbit. An Earth-facing antenna array 1412 is used to provide
reception of 30 GHz uplinks 1414 and also to provide transmission of
20 GHz downlinks 1416. The Earth-facing antenna array 1412 comprises
individual electronically steered phased-array antennas 1418 located
on eight mobile, fixed terminal satellite link M/FTSL antenna panel
sets 1420 and on the Earth-facing surface of the primary bus
structure 1422. Each M/FTSL antenna panel set 1420 has three
adjoining antenna facet panels 1424. The M/FTSL panels are deployed
at angles with respect to the Earth's surface that limit the required
steering angle from the satellite to the portion of the Earth surface
served by this antenna. Four intersatellite link ISL antenna arrays
1426 are located on the space-facing surface of the primary bus
structure 1422. Four individual ISL antennas 1428 make up each of the
ISL antenna arrays 1426. The ISL antennas 1428 are able to receive

and to transmit 60 GHz intersatellite links 1430. The 60 GHz
intersatellite links 1430 provide communication among the
constellation of Callingsats.TM..

Detailed Description Text - DETX (283):

The Astromast.TM. boom 1432 continues to extend to its full
length. The satellite antennas and electronics operate most
efficiently at low temperatures. They can most effectively dissipate
the heat generated in their operation by radiating this heat via the
back side of the M/FTSL antenna panel sets 1420 into "cold space"
which has an ambient temperature of approximately 4 degrees Kelvin.
If the radiation of the suns is allowed to impinge directly on the
back surface of the M/FTSL antenna panel sets, this increases the
effective ambient temperature, which would result in less efficient
thermal dissipation, a higher operating temperature, and less
efficiency. The present design uses the amorphous silicon solar
arrays 1438 as a sun shade to effectively shield the Callingsat.TM.
1410 from the sun and thus to reduce the effective ambient
temperature of the space into which the Callingsat.TM. 1410
dissipates heat. This is done by using amorphous silicon solar arrays
1438 that when fully extended on the Astromast.TM. boom 1432 between
the Callingsat.TM. 1410 and the suns and oriented perpendicular to
the suns, casts a shadow that completely covers the Callingsat.TM.
1410, including all antenna facet panels 1424. The amorphous silicon
solar array position that provides maximum shading also provides the
most efficient solar energy generation, since the array surface is
maintained perpendicular to the sun's rays. The extension of the
Astromast.TM. boom 1432 provides sufficient distance between the
primary bus structure 1422 and the amorphous silicon solar arrays
1438, which, in turn, furnishes the required radiation shielding for
the antennas 1418 and the ISL antennas 1428. In this embodiment, the
Astromast.TM. boom 1432 is approximately twelve meters long when
fully extended.

Detailed Description Text - DETX (285):

FIG. 127 also illustrates the expansion of the solar array storage
booms 1436 as the Astromast.TM. boom 1432 reaches its fully extended
length. The solar array storage booms 1436 are coupled to each other
using boom hinge mechanisms 1498. The solar array storage booms 1436
use the boom hinge mechanisms 1498 to pivot away from their parallel
stored position towards a coaxial arrangement.

Detailed Description Text - DETX (286):

FIG. 128 is an illustration 1500 which shows full extension solar
array storage booms 1436 and the outer antenna arrays 1454. The solar
array storage booms 1436 come into coaxial alignment with each other
as the boom hinge mechanisms 1498 that couple them pivot to their

extended positions. Each end of each solar array storage boom 1436 is coupled to a deployment mechanism 1508. In FIG. 128 the cantilever booms 1442 can be seen as they would be attached to the solar array storage booms 1436 in a parallel fashion between the deployment mechanisms 1508. The boom crossmast 1434 rotates to position the solar array storage booms 1438 correctly for expansion of the amorphous silicon solar arrays 1436. The pulse plasma thrusters 1444, the storage batteries 1446, and the shunt regulators 1448 are seen as they are located on the boom crossmast 1434.

Detailed Description Text - DETX (299):

FIG. 131 is a side view 1522 of a fully extended and deployed Callingsat.TM. 1410. This depiction shows how the advanced design of the Callingsat.TM. 1410 provides a large Earth-facing antenna array 1412 to provide a large volume of 30 GHz uplinks 1414 and 20 GHz downlinks 1416, and ISL antenna arrays 1426 to provide a large volume of 60 GHz intersatellite links 1430. This view also illustrates how the expandable Astromast.TM. boom 1432 is extended to position the amorphous silicon solar arrays 1438 correctly.

Detailed Description Text - DETX (329):

The service area offered by the preferred embodiment of the present invention, the Earth's entire surface, is divided into a grid of 180,000 cells, similar in concept to the cells of terrestrial cellular systems. As a general rule for cellular systems, the smaller the cell, the higher the user density that can be served and the more efficiently the assigned spectrum can be reused within a service area, resulting in a higher system capacity for a given amount of spectrum. The cells are identical 53.3 by 53.3 km squares, with an area roughly equivalent to a large cell in a terrestrial cellular system, but extremely small and efficient compared with other satellite systems. The preferred embodiment uses a spectrum-efficient modulation and coding scheme that yields a capacity of over 1400 simultaneous full-duplex 16 Kbps connections within any cell. This 16 Kbps rate is used as the basic channel because it is the minimum that will support the high-quality voice service expected from a modem network. This equivalent basic channel rate is used to simplify and clarify capacity calculations, although 16 Kbps channels can and will be aggregated into a smaller number of high-rate channels for broadband applications. For example, a 1.544 Mbps T1 line would consume the same network access capacity as almost 100 basic 16 Kbps channels.

Detailed Description Text - DETX (330):

One of the advantages of wireless service is that system resources can be shared among users so that a given number of channels can efficiently support the demands of a larger number of users. For

example, if the average user only needs a channel for 10% of the network's busy period (this usage level is referred to as 0.1 Erlang), then the preferred embodiment's 1400 channels per cell could support 14,000 users with a low probability that they will be blocked when they request a channel. Obviously, usage level has a large effect on capacity measured by "number of users;" the present invention uses a conservative estimate of 0.1 Erlangs per user.

Detailed Description Text - DETX (335):

System capacity depends entirely on a system of many satellites which uses a high preferred mask angle of at least forty degrees. This critical system parameter is only achievable through the use of a large number of satellites compared to previous proposed systems and of very high communications frequencies. Motorola's Iridium.TM. system, described in European Patent Application No. 891 184 58.2, is not designed to realize the system capacity and service levels that the present invention will achieve. Iridium.TM. is intended only as an adjunct or enhancement of conventional terrestrial cellular telephone service. Motorola's Iridium.TM. system is not designed to be a complete global communications system that is capable of supporting in excess of 2,000,000 simultaneous connections, representing over 20,000,000 users at typical business usage levels, and over 350 billion minutes of use per year. Only a system such as the preferred embodiment, which utilizes 840 satellites at a preferred minimum mask angle of forty degrees can accomplish these challenging objectives.

Detailed Description Text - DETX (345):

The angle measured upwards to the position of a satellite in the sky from the local horizon of a portable, mobile or fixed terminal or gateway.

Detailed Description Paragraph Table - DETL (17):

LIST OF REFERENCE CHARACTERS 10 End-to-end network model 12 First user terminal 14 First network interface 16 Calling network 18 Second network interface 20 Second user terminal 22 Operations traffic 24 User traffic 26 Single satellite 28 Orbital plane 30 Terminal 31 Keypad and display 32 Analog voice signal 33 Call-progress tones and display circuits 34 A/D converter 36 Digitized voice output 38 Speech encoder 40 Digital encoded speech 42 Encryption equipment 44 Encryption key 46 Signalling and control processor 48 Encrypted output 50 Sequence numbers 52 Destination addresses 54 Signal packets 56 Packet assembler 58 Packets 60 Error encoder 62 Transmit buffer 64 Transmitter 66 Power control circuitry 68 Frame and bit timing circuitry 70 Antenna 72 Uplink radio signals 74 Steering logic circuits 76 Downlink radio signals 78 Receiver 80

Address decoder 82 Terminal identifier information 84 Error detector
86 Header decoder 88 Signal packets 90 Speech packets 92 Packet
receive buffer 94 Timing and packet resequencing stage 96 Decryption
key 98 Security decryption circuit 100 Speech decoder 102 Echo
suppressor 104 Digital analog converter 106 Gateway antennas 108
Local receivers 110 Remote receivers 112 Local receivers 114 Remote
receivers 116 Receiver select logic 118 Fast packet switch 120
Incoming control circuitry 122 Outgoing control circuitry 124 Packet
Assembly and Disassembly interface (PAD) 126 Series of Packet
Assembly and Disassembly stages 128 DS-1 links 130 Access switching
machine 132 Test access circuitry 134 Control circuitry 136 Link for
spacecraft access 138 Switched traffic 140 Unswitched traffic 142
Link 144 Link 146 Clock 148 Operating system 150 DS-1 interface 152
Custom or standard interface 154 Outside telephone carrier 156 "Ping-
pong" diagram 158 Network 160 Satellite node 162 Intersatellite link
164 Gateway-satellite link (GSL) 166 Gateway interface 168 Operation
support system 170 Feature processor 172 Gateway switches 174
Database systems 176 Mobile terminal satellite link (MTSL) 178
Customer 180 Mobile terminal satellite link (MTSL) 182 Hand-held and
car phones 184 Fixed terminal satellite link (FTSL) 186 Subscribers
210 Terrestrial Antennas 210a Trapezoidal/Semi-conical embodiment of
antenna 210b Hemispherical embodiment of antenna 210c Cylindrical
embodiment of antenna 212 Trapezoidal/Semi-conical surface 212a Upper
portion of trapezoidal/semi-conical surface 212b Lower portion of
trapezoidal/semi-conical surface 214 Top circular surface 216 Bottom
circular surface 218 Circular antenna element 220 Conductive patch
222 Cross-slots 222a First slot 222b Second slot 224 Hemispherical
surface 226 Bottom circular surface 228 Right-circular cylindrical
surface 230 Top circular surface 232 Bottom circular surface 234
Nonconductive substrate layer 236 Ground plane layer 238 Five bit,
time delay phase shifter 240 11.25 degree delay line 242 22.50 degree
delay line 244 45.00 degree delay line 246 90.00 degree delay line
248 180.00 degree delay line 250 Hemispherical configuration with
dual frequency antenna elements 252 Upper hemispherical surface 253
Lower circular surface 254 Dual frequency antenna element 256 Upper
conductive layer 258 Lower conductive layer 259 Conductive via 260
Conductive via 262 Foam layer 264 Dielectric layer 266 Ground plane
layer 268 Receive circuit 270 Printed circuit four element subarray
272 Feeds 274 First radio frequency amplifier 276 First band pass
filter 278 Second radio frequency amplifier 280 Mixer 282 Source 284
Output of synthesizer 286 Third radio frequency amplifier 288 Decoder
290 Intermediate frequency band pass filter 292 Analog-to-digital
converter 294 Digital band pass filter 296 Threshold detector 297
Transmit circuit 298 Printed circuit four element subarray 300 Feeds
302 Amplifier 304 Encoder 306 Radio frequency source 308 Synthesizer
310 Alternate embodiment of miniaturized antenna 312 Top element 314
Radiating element 315 Soft substrate 316 Ground plane 317 Dummy
element 318 Top view 320 30 GHz printed circuit patch element 322 20
GHz patch element 324 Substrate layer 326 Cross-sectional side view
328 Foam layer 330 Ground plane 332 Cross-sectional view 334 Radome

335 Dummy element 336 Printed dual frequency printed circuit elements
337 Printed dual frequency printed circuit elements 338 Microwave
substrate 340 Feed networks and distribution circuits 342 Active
microwave components 344 Ground plane and support structure 410 Flow
chart of switching process 412 Orbital position information 414
Adaptive routing processor 416 Adaptive routing algorithm 418 "Next-
node-in-path-to-destination" output 420 Routing cache memory 422
Packets 424 Header 426 Payload 428 Input packet processor 430 Next
node routing tag 432 Destination node 434 Processed packet 436 Input
ports 438 Fast packet switch 440 Output port 442 Satellite switch
node 444 Circuit modules 446 Receiver 448 Demodulator 450 Bit/packet
synchronizer 452 Input packet control modules 454 Error detection
circuits 456 Packet tagging circuits 458 Local cache access 460
Network cache access 462 Control complex 464 Call control processor
466 Maintenance processor 468 Reload processor 470 Billing and
traffic processor 472 Satellite ephemerides processor 474 Local
routing and handover processor 476 Local routing cache 478 Routing
processor 480 Network routing cache 482 Communications processor 484
Spare processor 486 Steering processor 490 Output packet control
modules 492 Path history circuits 494 Error encoding circuits 496
Output packet control modules 498 Packet framing circuits 500
Modulator 502 Transmitter 504 32 .times. 1 packet priority
multiplexor 506 Serial input signals 508 Serial-to-parallel
converters 510 First-in, first-out buffering circuits 512 Status and
control circuits 514 Logic circuitry 516 Output queue status stage
517 Eight bit parallel bus 518 Priority router 520 8 .times. 16K low
priority first-in, first-out circuit 522 8 .times. 16K high priority
first-in, first-out circuit 524 Parallel-to-serial converter 526 150
MBIT/S serial output 528 Block diagram of fast packet switch 530
Serial inputs 532 1 .times. 32 self-routing switch module 534
32 .times. 1 asynchronous packet multiplexor 536 Schematic diagram of
1 .times. 32 self-routing switch module 538 Self-routing cell 540
Output side 542 Routed packets 544 Mobile/fixed satellite link 546
Radiating array 548 Feeds 550 Beam steering computer 552 Diplexer 554
Receive beam forming network 556 Bank of receivers

Detailed Description Paragraph Table - DETL (18):

558 First controller mux/demux/modem 560 Synthesizer 562
Frequency controller 564 Second controller mux/demux/modem 566 Bank
of transmitters 568 Transmit beam forming network 602 Footprints 602a
Footprint 602b Footprint 602c Footprint 604 Earth-fixed supercell 606
Earth-fixed cell 608 Cell pattern 610 Satellite footprint diagram 612
Column pair 614 Second and central column pair 615 Satellite
footprint overlaps 616 Rightmost column pair 617 Satellite footprint
gaps 618 Flow chart 619 Destination terminal 620 "Node" bits 622
"Call identification" bits 624 Cell ID map 626 Channel 628 Autonomous
orbit position determination software 630 Position/output beam map
632 Modified packet 700 Earth-facing antenna array 702 Hexagonal
antenna facets 704 Solar panel 706 Space-facing array 708 Space-

facing facets 709 Electronically steered beams 709a Set of beams 709b
Set of beams 709c Set of beams 710 Line-of-sight radio waves 712
Geometric plots 714 Geometric plots 715 Interior of antenna array 716
Schematic diagram of a GaAs MMIC time delay network 718 Active lens
720 Radiating elements 722 Time delay circuit 724 Feed 725 Time delay
steered array 726 Switch 728 Time delay path 730 Transmission lines
732 Amplifier 800 Satellite 801 Launch vehicle 802 Spacecraft
direction of travel 804 Longitudinal axis of solar panels 806
Spherical connectors 808 Tubular connectors 810 Gearsat .TM. 811
Schematic representation of a person two meters tall 812 Cylindrical
surface at periphery of Gearsat .TM. 814 Rectangular antenna panels
on cylindrical surface 816 Solar panels 818 Block diagram of
satellite subsystems 820 Bus 822 Communications Payload 824 Command
and Data Handling Subsystem 826 Electrical Power Subsystem 828
Attitude and Orbit Determination and Control Subsystem 830 Sun
sensors 832 Actuators 834 Propulsion Subsystem 836 Cabling Subsystem
838 Structure Subsystem 840 Mechanisms Subsystem 842 Thermal Control
Subsystem 844 Block diagram of satellite subsystems 846 Local area
network 848 Power Control Subsystem 850 Batteries 852 Power
Distribution Subsystem 854 Array switching link 856 Shunt regulators
858 Shunt radiators 860 Block diagram of satellite subsystems 862
Local area network 864 Bus 866 Payload 868 Telemetry and command unit
870 1750 microprocessor 872 Master oscillator 874 EDAT microprocessor
876 RISC microprocessor 878 Block diagram of satellite subsystems 880
Local Area Network 882 Acquisition sun sensors 884 Inertial
measurement units 886 Magnetometers 888 Attitude Control Electronics
unit 890 Reaction wheels 892 Magnetic torquers 894 Batsat .TM. 896
Central body of Batsat .TM. 898 Antenna and solar/thermal panel array
900 Antenna array 901 Antenna panel 902 Antenna panel 903 Antenna
panel 904 Antenna panel 905 Antenna panel 906 Antenna panel 907
Antenna panel 908 Antenna panel 909 Antenna panel 910 Solar/thermal
panel 911 Solar/thermal panel 912 Cables 914 Hinges 1000 Schematic
diagram showing orbit position determination 1002 Other satellite
1004 Time synchronizing signals 1006 Ground station receiver 1008
Ground station transmitter 1010 Doppler observation 1012 Block
diagram showing AOD 1014 Time and frequency measurements 1016 SV POS
1018 SV LOS 1020 RDSS PR packet 1022 Communication network 1024
Antenna control 1026 Position determination circuitry 1028
Communication link 1030 Data demodulation stage 1032 Frequency
synthesizer 1034 Oscillator 1036 Phase locked loop 1038 Pilot tone
1040 Time of perception of PR packet 1042 Time and frequency
synchronization 1044 Doppler signals 1046 AOD processor 1048 Pointing
direction signals 1050 Attitude determination processor 1052
Schematic diagram showing attitude determination 1100 Node hardware
architecture 1102 Common control stage 1104 Internode messages 1106
Internode messages 1108 Receivers 1110 Transmitters 1112 Link control
process 1114 Routing process 1116 Service demand 1118 Subscribers
1120 Routing tables 1122 Local processes 1124 Dynamic packet routing
method 1126 Router 1128 Packet routers 1130 Sorting network 1132
Transmitters 1134 Diffusion rate 1136 Diffusion rate 1138 Diffusion

rate 1140 Output module 1142 Switching architecture 1144 Signal flow 1146 System architecture 1148 Input Output Packet (IOP) Processor and Fast Packet Switch 1150 IOP 1152 Input Packet Processor 1154 IPP Common Control 1156 Pipe delay 1158 IPP four stage pipeline 1160 IPP Optimal Route Controller 1162 Message Communication 1164 128 .times. 128 Switch 1166 Switching Cell 1210 View of constellation 1211 Orbit 1212 Callingsat .TM. 1213 Simplified antenna elements 1214 View of footprint pattern over United States 1216 Footprint 1215 Earth-fixed cell footprint beams from Callingsat .TM. 1218 View of one footprint illuminating Earth-Fixed grid 1219 Earth-fixed cell beam 1220 Earth-fixed grid 1222 Enlarged view of Earth-fixed grid, supercell and cell 1224 Supercell 1226 Cell 1226 Target cell 1228 View of footprint formed by Callingsat .TM. 1230 Mask angle 1232 Altitude 1234 Maximum distance to footprint perimeter from Callingsat .TM. 1236 Diameter of footprint 1238 View of satellite footprints overlaps and gaps at equator 1240 Overlap for 40 satellites/orbit @ 1000 km spacing 1242 Overlap for 35 satellites/orbit @ 1142 km spacing 1244 Overlap for 30 satellites/orbit @ 1333 km spacing 1245 Distance between footprint centers 1246 Overlap 1248 Gap 1250 Potential gap strip 1252 Single coverage strip 1254 View of satellite footprints overlaps and gaps at 40 degree latitude 1256 Double coverage strip 1258 Sequential views of Callingsat .TM. providing service to one Earth-fixed cell 1260 Sequential views of Satellite-Fixed Cell system 1260a Sequential views of one Satellite-Fixed Cell 1261 Satellite using Satellite-Fixed Cell method 1262 Beams with no beam steering 1264 Earth-fixed cell footprint beam 1265 Satellite-fixed beam 1266 Low mask angle 1268 Flowchart showing packet processing 1270 Node 1272 Call ID 1274 Payload 1276 Index 1278 Cell ID Map 1280 Channel assignment 1282 Channel entries 1284 Cell entries 1286 Supercell entries 1288 AOD Software 1290 Position/Output Beam Map 1292 Output Beam Map 1294 Channel designation 1296 Cell designation 1298 Output beam designation 1300 Fast Packet Switch input 1302 Fast Packet Switch 1304 Fast Packet Switch output 1306 Channel assignment 1308 Cell assignment 1309 Packet buffer 1310 Transmitter 1311 Alternative hardware embodiment

Detailed Description Paragraph Table - DETL (19):

1312 View of cells being scanned 1314 Cell scan pattern 1316 View of scanning cycle 1318 Cell TDM 1320 Supercell SDM 1322 Scan cycle 1324 Transmit/Receive time 1326 Guard interval 1328 View of Channel Multiplexing 1330 Uplink 1332 Downlink 1334 Channel 1336 Time Interval 1338 Channel 1340 Time interval 1342 Bandwidth 1344 Perspective view of Callingsat .TM. in orbit 1346 Callingsat .TM. satellite 1348 Central octagonal panel 1350 Mast 1352 Solar cell and shade 1354 Intersatellite link antennas 1355 Domesat .TM. 1355a Space-facing antennas 1355b Earth-facing antennas 1355c Solar cells 1356 View of Callingsat .TM. from Earth 1358 Transmit antennas 1360 Receive antennas 1410 Callingsat .TM. satellite 1412 Earth-facing antenna array 1414 30 GHz uplinks 1416 20 GHz downlinks 1418 Antennas

1418a Uplink antennas 1418b Downlink antennas 1420 M/FTSL antenna
panel set 1422 Primary bus structure 1424 Antenna facet panels 1426
ISL antenna array 1428 Individual ISL antenna 1430 60 GHz
intersatellite links 1432 Astromast .TM. boom 1434 Boom crossmast
1436 Solar array storage boom 1438 Amorphous silicon solar array 1440
Inflatable boom 1442 Cantilever boom 1444 Pulse plasma thrusters 1446
Storage batteries 1448 Shunt regulators 1450 Perspective view of
assembled Callingsat .TM. 1452 Inner antenna array 1452A First inner
antenna array 1452B Second inner antenna array 1452C Third inner
antenna array 1452D Fourth inner antenna array 1454 Outer antenna
array 1454A First outer antenna array 1454B Second outer antenna
array 1454C Third outer antenna array 1454D Fourth outer antenna
array 1456 Component storage compartment 1458 Solar array attachment
structure 1460 Command and data handling subsystem 1462
Attitude/orbit determination and control subsystem 1464
Communications payload subsystem 1466 Front view of assembled
Callingsat .TM. 1468 Side view of assembled Callingsat .TM. 1470
Front view of Callingsat .TM. before launch 1474 Top cutaway view of
Callingsat .TM. in launch vehicle 1480 Bottom cutaway view of
Callingsat .TM. within launch vehicle 1482 Illustration of
Callingsat .TM. deployed in low Earth orbit 1484 Illustration of
deployed Callingsat .TM. with detached solar array storage booms 1486
Illustration of deployed Callingsat .TM. with extended Astromast .TM.
boom 1488 Depiction of expanding solar array boom and extension of
outer antenna arrays 1490 Antenna deployment hinges 1492 Inner
antenna panel on outer array 1494 Central antenna panel on outer
array 1496 Outer antenna panel on outer array 1498 Boom hinge
mechanism 1500 Depiction of extended solar array boom and extension
of inner antenna arrays 1502 Inside antenna panel on inner array 1504
Middle antenna panel on inner array 1506 Outside antenna panel on
inner array 1508 Deployment mechanism 1510 Depiction of inflating
solar arrays 1512 Photovoltaic cells 1514 Film substrate 1516
Photocurable chemical vapor 1518 Inflation gas 1520 Fully deployed
solar array 1522 Side view of fully deployed Callingsat .TM. 1524
Front view of fully deployed Callingsat .TM. 1526 Illustration of
fully deployed Earth-facing antenna arrays 1528 Alternate embodiment
of Earth facing antenna arrays 1530 Another embodiment of Earth
facing antenna arrays B Beam from satellite BP Battery pack for hand
held phone C Constellation of satellites E Earth EX Retractable
antenna mast in fully extended position F Fixed terminal G Gateway H
Spring Loaded, Self-Latching Hinges K Keypad L LCD display screen LV
Launch vehicle LVI Launch vehicle interior M Mobile terminal P
Portable terminal PDE Payload dynamic envelope PN Person S Satellite
ST Retractable antenna mast in stowed position TEL Hand-held portable
telephone T Telephone Z Zenith

Other Reference Publication - OREF (12):

     V.H. MacDonald, "Advanced Mobile Phone Service: The Cellular
Concept", 1979, pp. 15-41, published in The Bell System Technical

Journal, vol. 58, No. 1, Jan. 1979.